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Geology of the Eastern Prebetic Zone at the Jumilla region (SE Iberia)

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ABSTRACT

This article presents a geological map and cross-sections at 1:50,000 scale covering an area of 609 km² of the Eastern Prebetic Zone (SE Iberia). The structure of the studied area is characterized by an NW-directed fold-and-thrust belt and inactive salt diapirs that are parallel to the ENE- to NE-regional trend of the eastern Betic Cordillera. This regional trend is locally disrupted by the NW-trending Matamoros Basin, which is flanked by the active Jumilla and La Rosa diapirs. The geological map, the cross-sections and the outcrop observations support the hypothesis that the major Mesozoic rifting phase affecting the Eastern Prebetic Zone occurred during the Upper Jurassic to Santonian times coeval to the development of extensional basins in the Western Tethyan area. The proximal part of this passive margin was subsequently incorporated into the external part of the Betic thin-skinned fold-and-thrust belt. The Upper Cretaceous to Cenozoic tectonic evolution of the study area encompassed the following stages: a Campanian to Aquitanian NW-directed contraction; a Burdigalian to upper Miocene extensional reactivation of the main subsalt faults; and a Serravallian NW-directed contractional reactivation. In this scenario, the combined effect of the previous contractional reactivation of pre-existing salt structures together with the Miocene subsalt extension triggered passive salt extrusion of the La Rosa and Jumilla diapirs.

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KEYWORDS

Salt-bearing passive margin; subsalt extension; thin-skinned shortening; Eastern Prebetic Zone

1. Introduction

The Betic Cordillera, located in the southwestern part of the Alpine fold-and-thrust belt (Figure 1), is the result of the N–S to NNW–SSE convergence between the major Eurasian and African plates during the Upper Cretaceous to Present times (De Galdeano, 1990; Dercourt et al., 1986; Dewey, Helman, Knott, Turco, & Hutton, 1989). The eastern part of this cordillera (Figure 2) is subdivided from north to south into the External and Internal Betic Zones (Balanyá & García-Dueñas, 1987; Fallot, 1948). The Internal Betic Zones (e.g. the Malaguide Complex outcropping in Sierra Espuña, Murcia) consist of an allochthonous stack of thrust sheets composed mainly of a thick succession of Triassic to Early Miocene sedimentary rocks (De Jong, 1990; Egeler & Simon, 1969; Martín-Martín et al., 2006; Torres-Roldán, 1979). The External Betic Zones correspond to an orogenic wedge composed by an NW- to NNW-directed fold-and-thrust belt that is detached from the Iberian basement along the Upper Triassic evaporites (Platt et al., 2003). Locally, diapirs made up by these evaporites pierce the thin-skinned thrust sheets that constitute the fold-and-thrust belt (De Ruig, 1995; Martínez del Olmo, Motis, & Martín, 2015; Moseley, 1973).

During the Mesozoic, the External Betic Zones were represented by the proximal part of the NE-trending South Iberian passive margin (i.e. northern conjugate passive margin of the Alpine Tethys, Bernoulli & Lemoine, 1980; Dewey, Pitman, Ryan, & Bonnin, 1973; Ziegler, 1982). The Alpine Tethys resulted from the Lower to Middle Jurassic rifting followed by the Callovian oceanic flooring that separated the Eurasian and African plates (Schettino & Turco, 2011). However, in the External Betic Zones, the most important rifting phase occurred later allowing the deposition of the Upper Jurassic to Santonian syn-extensional sediments unconformably above the pre-extensional Lower and Middle Jurassic carbonates (De Ruig, 1992; García-Hernández, López-Garrido, Rivas, Sanz de Galdeano, & Vera, 1980; Hanne, White, & Loneragan, 2003; Vera, 2001). During the Upper Jurassic to Santonian, the External Betic Zones (Figure 2) were subdivided into the northwestern Prebetic Zone and the southeastern Subbetic Zone (García-Hernández et al., 1980). According to the thickness and the stratigraphy of the Mesozoic units, the Prebetic Zone is divided, from NW to SE, into the External and Internal Prebetic (De Ruig, 1992; García-Hernández et al., 1980).

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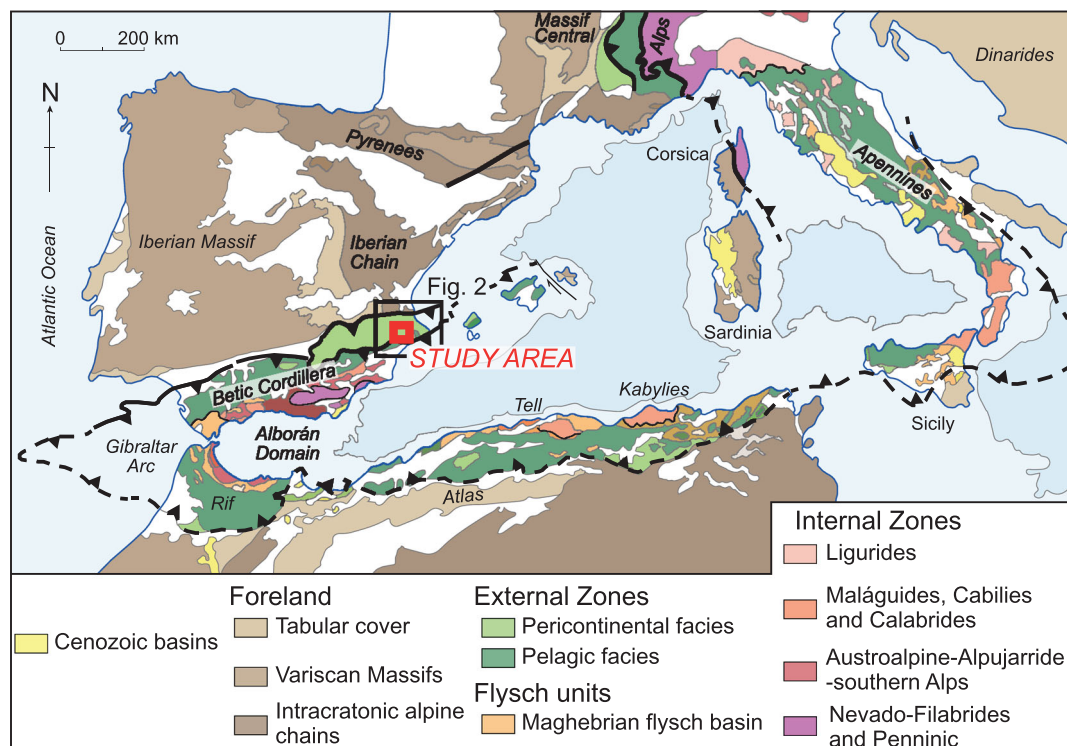


Figure 1. Geologic map of the Southern termination of the Alpine fold-and-thrust belt in the Western Mediterranean (modified from Vera, 2004).

This study presents a detailed geological map of the Jumilla region, comprising part of the External and Internal Prebetic (see the red square in Figure 2). The structure of the studied area is characterized by an NW-directed fold-and-thrust belt and inactive salt diapirs that are parallel to the ENE- to NE-

regional trend of the Betic Cordillera and the Mesozoic South Iberian passive margin. However, the ENE- to NE-regional trend is locally disrupted by the NW-trending Mesozoic to Cenozoic Matamoros Basin, which is flanked by the active Jumilla and La Rosa diapirs.

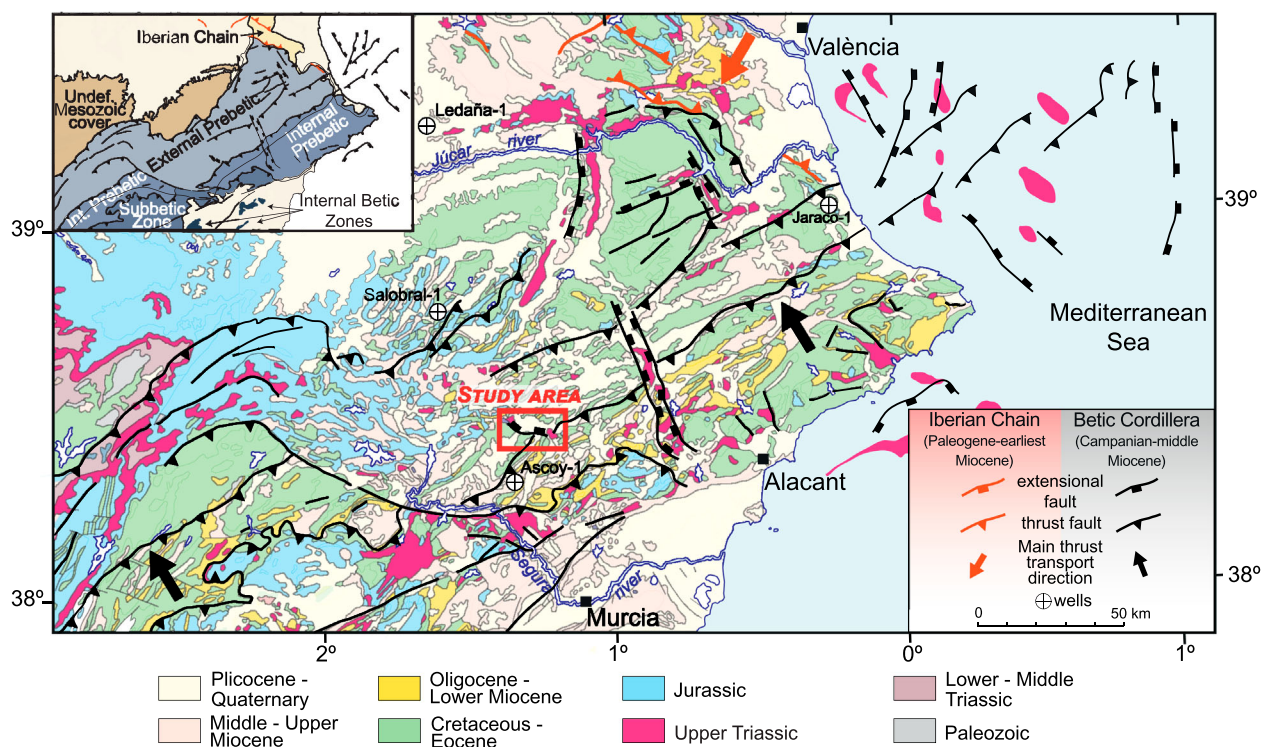


Figure 2. Geologic and tectonic maps of the Eastern Betic Cordillera (modified from IGME 1M scale Geological map).

2. Methods

The geological map of the Eastern Prebetic Zone at the Jumilla region covers 609 km². The map was constructed as part of a PhD dissertation, with more than six months of fieldwork distributed in three years. The cartographic base consists of 1:50,000 topographic maps, digital terrain models (DTM's at 5 m cell size) and orthophotographs (with 0.25 m pixel resolution) provided by the *Centro Nacional de Información Geográfica* (C.N.I.G.) of the Spanish Government. Geological mapping was performed at 1:5000 scale. Traces of the outcropping geological surfaces (mostly bedding and faults) were mapped in the field using the orthophotographs and up to 6000 dip data were collected using a compass-clinometer. The field data were geo-referenced and transferred into a three-dimensional digital environment (Move™ software from Midland Valley). In this scenario, the digital outcrop characterization using the methodology developed by Fernández (2005) allowed us to complete the mapping of the geological surfaces. The northernmost part of the geological map (i.e. northern part of Sierra de las Cabras unit) is also represented on the map, but it was mapped at less detail than the rest of the area. The mapping of this part benefited from previous works of Baena (1979) and Gallego Coídurás, García Domingo, López Olmedo, and Baena Pepez (1981). The fault symbols depicted on the *Main Map* reflect the stratigraphical relationship of hanging wall to foot-wall (i.e. thrust fault: older over younger; extensional fault: younger over older).

The *Main Map* is accompanied by three cross-sections at 1:50,000 scale. Their orientation was chosen to depict the main structural features of the studied area. Using Move™ software, dip data were projected into the cross-section lines according to the projection vectors calculated by the definition of cylindrical dip-domains. Interpolation and extrapolation of data were also performed using Move™ software. The geometry of the faults was interpreted according to the stratal architecture located in its hanging wall.

3. Results

3.1. Stratigraphy

The stratigraphic units depicted on the map are classified into four well-differentiated main groups of rocks according to the tectonic events that controlled their deposition (Figure 3).

The pre-extensional succession is subdivided into three main groups of rocks Paleozoic to Middle Triassic, Upper Triassic and uppermost Triassic to Middle Jurassic in age, respectively. The Paleozoic to Middle Triassic unit, which does not crop out in the study area, is located underneath the main detachment

(Upper Triassic salt) and is therefore considered mechanical basement. Despite this, the analysis of the stratigraphy based on the Salobral-1 and Jaraco-1 wells (see wells location in Figure 2) reveals Middle Triassic marine carbonates (~300 m thick) and Lower Triassic detrital continental rocks (~670 m thick) unconformably overlaying meta-sedimentary quartzites Silurian in age (Lanaja et al., 1987). The Upper Triassic unit is mostly characterized by halite with minor intercalations of volcanic, carbonate and detrital rocks (Ortí, 1974). In the study area (*Main Map*), this unit acts as the principal detachment decoupling the suprasalt cover from the subsalt basement. Its preserved normal stratigraphy and original thickness are difficult to reconstruct because it is highly deformed by diapiric structures (e.g. La Rosa, Jumilla and Carxe diapirs). Nevertheless, based on well data and composite outcrop sections along the Eastern External Betic Zones, the original Upper Triassic salt thickness is estimated to be ca. 600–700 m (Bartrina et al., 1990; De Torres & Sánchez, 1990). The uppermost Triassic to Middle Jurassic rocks consist of two cartographic units conformable lying above the Upper Triassic salt: the uppermost Triassic – Lower Jurassic mudstones and dolostones and the Middle Jurassic dolostones and oolitic limestones. This unit crops out only in the Sierra de las Cabras, partially in the northern part of Sierra del Carxe and in the southeastern part of the study area (*Main Map*). According to outcrop scale observations and the stratigraphy based on the Ascoy-1 well (see its location in Figure 2), this unit thickens towards the SE: ~240 m in this part of the External Prebetic to ~370 m in the Internal Prebetic. In the northwestern part of the study area (Sierra de las Cabras), a low angle unconformity and hard grounds Callovian – Oxfordian in age are located above the Middle Jurassic rocks. This unconformity (Figure 3) is interpreted as the onset of the major extension that affected this segment of the South Iberian margin (García-Hernández et al., 1989).

The syn-extensional succession consists of three main groups of rocks: Upper Jurassic, Neocomian to lower Albian and upper Albian to Santonian in age, respectively. The Upper Jurassic group consists of marine marly limestones, mudstones and oolitic dolostones unconformable lying above the uppermost Triassic to Middle Jurassic unit. It is subdivided into two cartographic units Oxfordian and Kimmeridgian – Tithonian in age (Vilas et al., 1982). This unit crops out in the northern part of the study area (i.e. Sierra de las Cabras) and in the northern part of the Sierra del Carxe (*Main Map*) showing a thickness increase from ~300 m in the External Prebetic to ~1700 m in the Internal Prebetic (Azéma, 1977; García-Hernández et al., 1980). The second group of rocks (Neocomian to lower Albian in age) is mainly composed by shallow water limestones, calcarenites, bioclastic calcarenites

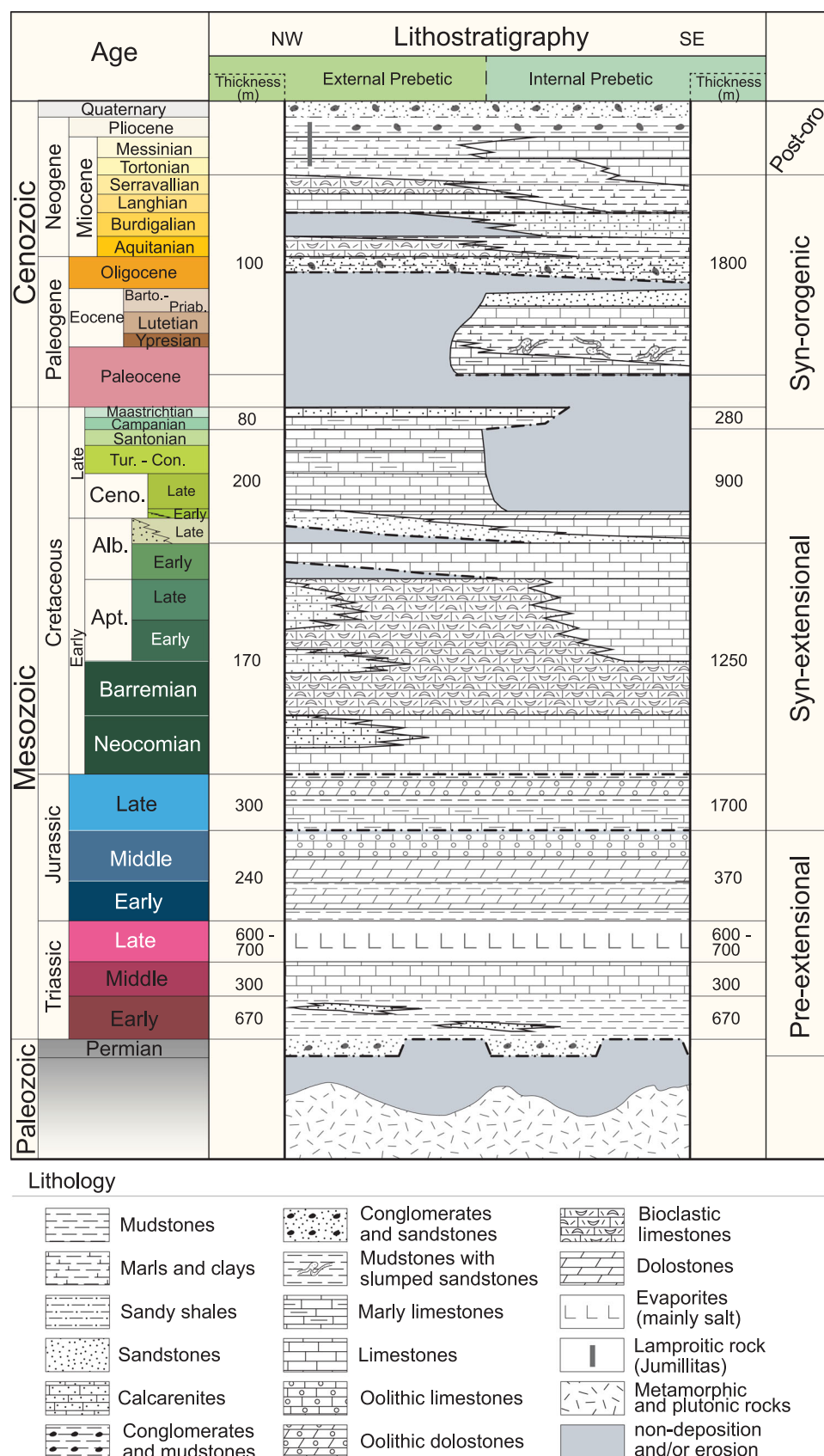


Figure 3. Lithostratigraphic chart of the sedimentary facies variation across the External and Internal Prebetic in the Jumilla region. After López-Garrido, 1971; Moseley, 1973; von Hillebrandt, 1974; Ortí, 1974; Martínez del Olmo, Benzaquen, Cabañas, & Uralde, 1975; Azéma, 1977; Rodríguez-Estrella, 1977; García-Hernández et al., 1980; Vera et al., 1982; Vilas, Arias, Elizaga, García de Domingo, & López-Olmedo, 1982; Lanaja, Querol, & Navarro, 1987; Bartrina, Hernández, & Serrano, 1990; Arias, Masse, & Vilas, 1993; Vilas, Martín-Chivelet, & Arias, 2003; Guerrero et al., 2014.

and siliciclastics lying unconformably above the Upper Jurassic unit (Arias et al., 1993; Vilas et al., 1982). This group has been subdivided into four cartographic units (Neocomian – Barremian, lower Aptian, upper Aptian and lower Albian in age) cropping out in the northern part of the Sierras Larga-Sopalmó and Carche and also in Sierra de Santa Ana and Peña Rubia (Main Map). In general, this group thickens towards the SE being ~170 m thick in the External Prebetic and ~1250 m thick in the Internal Prebetic. The third group, upper Albian to Santonian in age, lays unconformable above the previous units and has a more homogeneous carbonate facies association. It has been subdivided into seven cartographic units corresponding to the sedimentary formations defined by Martín-Chivelet (1992): the upper Albian sands (Utrillas sands Fm.), the upper Albian limestones (Jumilla Fm.), the lower Cenomanian marls (Villa de Ves Fm.), the lower Cenomanian dolostones (Alatoz Fm.), the upper Cenomanian limestones (Moratillas Fm.), the Turonian – Coniacian marly limestones (Alarcón Fm.) and the Santonian massive limestones (Sierra de Utiel Fm.). According to outcrop scale observations and well data, the upper Albian to Santonian group thickens towards the SE having an average thickness of ~200 m in the External Prebetic and ~900 m in the Internal Prebetic (Vilas et al., 2003). Locally in the External Prebetic, the Turonian to Santonian succession thickens suddenly related to halokinetic processes (e.g. Sierra del Molar and Buey). In the southern part of the Sierra del Carche, the presence of an erosive unconformity at the base of the Campanian rocks and a regressive general trend from hemipelagic to continental facies is interpreted as the onset of the contractional deformation probably related to the Pyrenean Orogeny and the incipient Betic compression (Andeweg, 2002; Guerrero et al., 2014; Martín-Chivelet, Giménez, & Luperto Sinni, 1997; Rodríguez-Estrella, 1977; Vilas et al., 2003).

The syn-orogenic succession consists of two main groups of rocks: Campanian – Maastrichtian and upper Paleocene – Serravallian. The first group is subdivided into two cartographic units corresponding to the sedimentary formations defined by Martín-Chivelet (1994): the Campanian marly limestones (Carche Fm.) and the Maastrichtian sandy limestones (Molar Fm.). This group displays a moderate thickening trend to the SE being ~80 m thick in the External Prebetic and ~280 m thick in the Internal Prebetic. Locally in the External Prebetic, this unit thickens related to halokinetic processes (e.g. Sierras del Molar and Buey). The Cenozoic succession is well developed in the Internal Prebetic (Main Map) and involves nine cartographic units made up of: upper Paleocene marly limestones and slumped sandstones; Ypresian green clays and marls; Lutetian nummulitic limestones; Bartonian – Priabonian sands and clays; Oligocene

conglomerates, sandstones and marls; Aquitanian bioclastic limestones and marls; Burdigalian calcarenites; Langhian limestones and marls; and Serravallian bioclastic calcarenites and marls. South of the Sierras Larga-Sopalmó and Carche, the Burdigalian to Langhian succession thicken towards the SE and display growth strata geometries related to the subsalt extensional reactivation of the same age. The complete syn-orogenic succession is up to ~100 m thick in the External Prebetic increasing to more than ~1800 m in the Internal Prebetic.

Finally, the post-orogenic succession consists of Tortonian to Quaternary rocks. This succession is subdivided into six cartographic units made up of: Tortonian white marls and limestones; Messinian limestones and marls; Pliocene red conglomerates, sandstones and sands; Pliocene lamproitic rocks; Quaternary alluvial; and Quaternary colluvial (von Hillebrandt, 1974; Guerrero et al., 2014). The deposition of this succession was mainly controlled by extension accommodated by the NE-dipping Maestre subsalt fault (Figure 4(a)). In addition, upper Miocene to Quaternary growth stratal geometries adjacent to the La Rosa and Jumilla diapirs suggest passive diapirism coeval to the deposition of these sediments (Figure 4(b–e)).

3.2. Structure

Based on the stratigraphic thickness of the sedimentary succession and the wavelength of the ENE-trending folds, the study area can be subdivided from NW to SE into three different units: Sierra de las Cabras, Jumilla and the Casas del Puerto-Torre del Rico units. The first two units are located in the External Prebetic, and the third one is located in the Internal Prebetic (Escosa, Roca, & Ferrer 2018).

The Sierra de las Cabras unit is characterized by short wavelength and symmetric NE-trending folds involving a thin Jurassic to upper Cenomanian succession unconformably overlain by Serravallian and Tortonian deposits. According to the fold geometry and the thickness of the involved sedimentary successions, it is interpreted that these are detachment folds cored by Upper Triassic salt. Considering the position of the fold hinges, the detachment is interpreted to be horizontal being located between the 0 and 100 m below the sea level. Southeast from this area, the Jumilla unit includes a Lower to Middle Jurassic succession with an assumed constant thickness (García-Hernández et al., 1980) overlain by the Upper Jurassic to Quaternary rocks displaying thickness changes across the area. This sedimentary succession is deformed by NE-trending narrow anticlines and broad synclines and by suprasalt faults dipping in general towards the northwest and southeast. According to the stratigraphic thickness, the wavelength of the folds and the position of the fold hinges, it is interpreted that



Figure 4. (a) Oblique Google Earth® image of the Jumilla Region with the location of the main structural and geomorphological features, the Matamoros Basin and La Rosa and Jumilla Diapirs. (b) Vertical to overturned upper Miocene sandstones and marls in the southern margin of the Jumilla Diapir (see location in Figure 4(a)). (c) Panoramic view of the La Rosa Diapir from Sierra del Carche (see location in Figure 4(a)). (d) Edge of La Rosa Diapir where Upper Triassic clays and gypsum are in contact with highly deformed Quaternary sediments. (e) E-dipping white marls and sandstones probably Tortonian – Messinian in age adjacent to the Jumilla Diapir.

the main detachment is horizontal being located at 800–1000 m below the sea level. In this unit, the lateral continuity of the NE-trending structures is interrupted by the Matamoros Basin (Figure 4(a)) which occupies an elongated NW-trending area extending from the Jumilla Diapir to the La Rosa Diapir (Figure 4(b,c)).

South of the previous unit, the Casas del Puerto – Torre del Rico unit is characterized by a thicker Upper Jurassic to Campanian succession and a complete Paleogene to Miocene sequence that is not present in the northern units. At the northwestern limit of the Sierras Larga-Sopalmo and Carxe, there is a system of NW-directed thrust faults affecting a thinned succession of Upper Jurassic to middle Miocene rocks. From here to the south and according to the stratigraphic thickness and the dip attitudes, the general structure of this unit can be interpreted as a broad monocline followed by a nearly horizontal panel. The base of the horizontal panel of this monocline could be located between –3200 and –5000 m below the sea level slightly dipping towards the southeast.

4. Discussion

The Eastern Prebetic Zone at the Jumilla region is characterized by a well exposed uppermost Triassic to Quaternary sedimentary succession. The geometrical analysis of the Mesozoic to Cenozoic structures in these units allows inferring a progressive SE-deepening of the Upper Triassic regional detachment associated with NE-trending basement steps. From NW to SE, these basement steps are interpreted to be controlled by the SE-dipping Jumilla and Sopalmo-Carxe subsalt faults. In the NW-trending Matamoros Basin, the analysis of surficial dip attitudes allows inferring that this basin is controlled by the NE-dipping Maestre Fault. The age of the associated growth stratal geometries of the suprasalt cover along the faulted blocks allows constraining the age of the faulting. Considering this, the Jumilla, Sopalmo-Carxe and the Maestre subsalt extensional faults were active during the Upper Jurassic to Santonian and were later extensionally reactivated during the Burdigalian to Langhian. The base of the syn-contractional sediments (i.e. Campanian unconformity) over the hanging wall of the subsalt faults show similar or less topographic elevation compared with the same syn-contractional sequence over their footwalls. Therefore, these evidences suggest that basement faults were not positive inverted, and thus in the study area, a thin-skinned inversion model needs to be assumed during the Betic compression.

These observations together with the sequential restoration of the extensional structures led to interpret that in the Eastern Prebetic Zone, the Upper Jurassic to Santonian extensional deformation affecting the

subsalt basement and the suprasalt cover was decoupled by the Upper Triassic salt. This implied that extension within the sedimentary cover was partially controlled by subsalt faults and partially by thin-skinned tectonics represented by listric suprasalt faults and piercing diapirs. This agrees with regional stratigraphic and structural evidences along the Eastern Prebetic Zone supporting the existence of a Mesozoic phase of extension (De Ruig, 1995; García-Hernández et al., 1989; Pedrera, Marín-Lechado, Galindo-Zaldívar, & García-Lobón, 2014; Vilas et al., 2003). However, ophiolites Middle Jurassic in age outcropping in the Internal Betic Zone demonstrates that the Southern Iberian margin was already a passive margin with the oceanic crust at this time (Puga et al., 2011). Extension in the South Iberian margin which took place between the Lower and Middle Jurassic was clearly connected with the opening of the Central Atlantic Ocean to the west (De Jong, 1990; Srivastava et al., 1990). Therefore, the following Upper Jurassic to Santonian extension could be related to the continued opening of the Central Atlantic and synchronous development of extensional basins in the Western Tethyan area (Hanne et al., 2003; Ziegler, 1989). Examples of Mesozoic extension (i.e. post Alpine Tethys rifting) are also documented in the Eastern Iberia (e.g. Columbrets Basin, Roca, Salas, & Guimerà, 1994), in the Organyà Basin (García-Senz, 2002) or along the Maghrebian margin represented by E–W rifting in Tunisia (Guiraud, 1998) and the Riffian – Tellian troughs (Wildi, 1983). Therefore, we interpret that the Upper Jurassic to Santonian extension is limited to the eastern parts of the South Iberian margin, and this process is independent from the formation of the Alpine Tethys.

The subsequent Betic compression was governed by thin-skinned shortening detached along the Upper Triassic salt which deformed the sedimentary cover and diapirs. In the study area, two major contractional events Campanian – Aquitanian and Serravallian in age are identified. The Campanian – Aquitanian contractional deformation appeared to be absorbed by diapir squeezing. Afterwards, in the Serravallian stage, the suprasalt cover together with the squeezed salt structures was contractionally translated towards the NW. However, the study area was affected by a Burdigalian to upper Miocene extensional reactivation of the main subsalt faults (i.e. Jumilla, Sopalmo – Carxe and Maestre faults). In the Eastern Prebetic Zone, this extension was mainly SW–NE and in the study area was conducted by the NE-dipping Maestre Fault. As a result, a thickened Miocene succession was deposited in the Matamoros Basin. This late extension could be related to the late Oligocene to Miocene extension that took place in the western Mediterranean region, in the Alboran Sea and in the Valencia Trough (Hanne et al., 2003; Maillard & Mauffret, 1999; Roca & Guimerà, 1992; Torné & Banda, 1992). In addition, the

combined effect of the Campanian to Aquitanian contractional reactivation of pre-existing salt structures and the Miocene extensional reactivation conducted by the NE-dipping Maestre Fault, triggered passive salt extrusion of La Rosa and Jumilla diapirs (Figure 4(b,c)). In this scenario, according to the Tortonian to Quaternary growth strata located adjacent to these diapirs (Figure 4(d,e)), salt was evacuated from beneath the Matamoros Basin to the rising diapirs creating sedimentary space for the deposition of the Miocene to Quaternary units.

5. Conclusions

This work presents a new detailed geological map of the Eastern Prebetic Zone at the Jumilla region that has facilitated the construction of cross-sections and a sequential restoration illustrating the interpretation of the tectonic evolution of the area. The geological map, the cross-sections and the outcrop observations support the hypothesis that the major Mesozoic rifting phase affecting the Eastern Prebetic Zone occurred during the Upper Jurassic to Santonian times coeval to the development of extensional basins in the Western Tethyan area. The proximal part of this passive margin was subsequently incorporated into the external part of the Betic thin-skinned fold-and-thrust belt. The Upper Cretaceous to Cenozoic tectonic evolution of the study area was characterized by: a Campanian to Aquitanian NW-directed contraction; a mainly Burdigalian to upper Miocene extensional reactivation of the main subsalt faults; and a Serravallian NW-directed contractional reactivation of the thin-skinned thrust faults. In addition, the Campanian to Aquitanian contractional reactivation of pre-existing salt structures together with the Miocene subsalt extension triggered passive salt extrusion of the La Rosa and Jumilla diapirs coeval to the deposition of the Miocene to Quaternary units.

Software

The **Main Map** was produced using Move™ software from Midland Valley which was used to ensemble the digital terrain models (DTM), the orthophotographs and to digitize the lithological contacts and the main structures mapped in the field. The cross-sections were also constructed and restored using Move™ from Midland Valley. Final editing and PDF construction were made using Adobe Illustrator™.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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